THE EISENHOWER LIBRARY
3 1151 02803 9315

MORAVIA
SPEC. COLL.

155037

Library

1876

of the Johns Hopkins University

JHU THESIS
McGlone,
Carter I
1907
c.1

THESIS.

ON THE

ANATOMY AND LIFE HISTORY

of

[illegible]

by

[illegible]

....

DISSERTATION SUBMITTED TO THE
BOARD OF UNIVERSITY STUDIES
OF THE
JOHNS HOPKINS UNIVERSITY
IN CONFORMITY WITH THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY.
JUNE 1907.

INDEX.

Introduction.
    Systematic position.
    Range and habitat.
Methods.
        Collecting.
        Experimentation.
        Artificial fertilization.
        Rearing of larvae.
        Killing and preservation.
        Dehydration and infiltration.
        Sectioning and staining.
        Preparation of adult material.
Note on abnormal tests of animals reared in aquarium.
Behavior.
        Feeding.
        Formation of "sign"
        Tactile and visual reactions.
        Reaction to heat.
Anatomy.
    External characters.
        Outline and apertures.
        Petaloids.
        Plates.
        Apical system.
        Tubercles.
        Spines.

Internal anatomy.

- Digestive organs.
- Accessory organs of digestion.
- Oral structures.
- Tube feet.
- The reproductory organs.
- Axial sinus.
    - Position
    - Structure.

Fertilization and segmentation.

- The unripe egg.
- The ripe egg.
- Entrance and advance of the sperm.
- Fusion of the nuclei.
- Prophase and Metaphase.
- Anaphase and Telophase.

Embryology.

- The first twenty-four hours.
    - Early segmentation.
    - The blastula stage.
    - The gastrula stage.
    - Origin of the skeleton.
    - Origin of the coelomic pouches.
    - Further development of the enteron.
    - The larva of twenty-four hours.

The development of the enterocoelomic cavities.
  Origin of the arms.
  Excretory bodies.
  Differentiation of the left entero coelomic cavity.
  The definitive larva.
  Larval musculature.
  Differentiation of the right enterocoelomic cavity.
  Development of the hydrocoele ring.
  The two pore canals.
  Larval nervous system.
The development of the Echinoid rudiment.
  The epineural folds.
  Origin of the dental sacs.
  Development of the nerves.
  Metamorphosis.
Summary [illegible]
Conclusion.

NOTES ON THE [illegible] AND LIFE HISTORY OF
MOIRA ATROPOS.[1]

Moira atropos, A. Agassiz, the Sea-Mouse, is an exocyclic echinoid which is included in the sub-order Petalosticha, and is classed with many other genera in the family Spatangidae.[2]

---

[1] During the summer of [illegible], at the Marine Laboratory of the United States Bureau of Fisheries, Beaufort, N. C. the Director, Dr. Caswell Grave, at the instance of Professor W. K. Brooks, suggested the study of the life history of Moira atropos, an irregular echinid which is very abundant on the shoals of the harbor. Further work was performed in the Biological Laboratory of the Johns Hopkins University. I am indebted to Dr. W. K. Brooks, as teacher, for his oversight during the progress of this work. Dr. E. A. Andrews has kindly assisted me in technical difficulties. Dr. Caswell Grave has given me the benefit of his experience in the embryology of echinoderms. I am under obligations to the Hon. Geo. M. Bowers, United States Commissioner of Fisheries for the privileges of the Beaufort Laboratory. Dr. H. V. Wilson, director of the Beaufort Laboratory during [illegible] placed at my disposal every convenience for the prosecution of the work. Professor Alexander Agassiz, Dr. C. Grave, and Dr. [illegible] have assisted me with illustrations.

[2] A. Agassiz (1)

The range of Moira atropos is from North Carolina to the West Indies. It has been collected from depths of 80 fathoms. At Beaufort N. C. the animal has been dredged occasionally outside the inlet where the average depth is about ten fathoms. However, it is most numerous on the various shoals of the harbor. It has its home in the silt of the shoals against which the river currents first come in contact. Regions of coarser materials, reefs of oyster, and the gravel and sand of the seaward side are never inhabited by Moira. The fine mud renders movement less difficult and less dangerous, as the test is very thin. The surface of the mud is covered with an abundant growth of diatoms, an important constituent of the food of the animal. Figure 1 is a diagram showing the animal and its surroundings.

METHODS.

The animals were dug on the shoals at low water, and kept in the laboratory in running sea-water until needed. The presence of the animal was indicated by the "sign" which will be described later. Up to the time when I successfully fertilized artificially the eggs of Moira, there had been but one successful attempt, by Prof. [illegible], but I am inclined to believe it was an exceptional case, as at the hour at which the earlier reports state the eggs were fertilized, I have found it impossible to get any results. Further attempts by other workers were failures as [illegible]

....

1. Records of the Beaufort Laboratory [illegible].

were unattainable. For example in the summer of 19[illegible] I made various experiments to discover the time or condition under which ripe eggs might be obtained, or the animal forced to mature eggs. Fertilizing on the surface, attempts to excite the emission of the sexual products through the presence of both sexes or by placing large quantities of sperm in sea-water which contained many animals, and attempts to hasten maturation by allowing the animal to sicken in stagnated water, were ~~[illegible]~~ failures. Finally I began the experiment of opening females within the laboratory at different hours. Then I discovered that the eggs mature during the night, for I have succeeded in getting mature eggs from females from 3.00 A. M. until 7.00 A. M., about which time they are evidently discharged.

At daylight the animals were opened and the gonads removed. The sexual products were then examined under the microscope. If males, the testes were placed in a tumbler of filtered sea-water. After several tests of unobserved maturity had been removed, the remaining males were discarded. If the eggs proved to be matured, the ovary was placed in a tumbler of sea-water. Severe maceration was seldom necessary as the ripe eggs streamed from the external [illegible]. Usually only a few mature females were found. A record which was kept of two hundred and twenty-four individuals, which were

---

1. [illegible] (16)

collected on three different days, yielded a hundred and fourteen males, twenty-three immature females, and [illegible] females with ripe eggs. In [illegible], [illegible] were from a jar which was kept in the laboratory in running seawater thirty-eight hours before they were opened. Great care was exercised to keep utensils and instruments free from contamination. In addition two sets of instruments were employed, one set for each sex, to prevent premature fertilization. The remains of the gonads were removed from the [illegible]. The eggs were decanted, when they had settled, and [illegible] in suspension, in order to get a pure collection of eggs. To fertilize the eggs several pipettes of diluted sperm were added to a finger-bowl of eggs and the water agitated. After the eggs had settled the excess of sperm was removed by successive decantings. Decanting was repeated at intervals of one hour. After the blastulae began to swim at the surface they were similarly decanted. Finally, the swimming blastulae were placed in [illegible] dishes.

The further culture of the larvae was successfully conducted by the use of methods devised by Grave.[1] A diatomaceous ooze is dredged about the inlet at Beaufort, N. C. and placed in aquaria [illegible] four weeks before the cultures are needed. The aquaria are covered and placed in the laboratory. A rich culture of diatoms appears on the surface of

---

1. C. Grave. (1)

the sun, this culture invades the surface of the glass and extends to the water line. When the animals are required, the ooze is removed, and the jar cleaned with fresh sea-water, care being taken not to remove those diatoms which adhered to the sides. The jars are filled with fresh sea-water and a few pipettes of diatoms in sea-water added. The diatoms and inorganic particles sink to the bottom. All sea-water used for any purpose was drawn at high-tide. For rearing larvae it is imperative that all the sea-water be filtered through cotton to remove the copepods which voraciously devour the larvae. When the larvae are twenty-four hours old they are placed in these aquaria. When the larvae brush against the sides they secure food from the culture of diatoms which grow there. Diatoms were dropped through the masses of larvae, twice a day. The changing of sea-water was accomplished with little difficulty by the fact that the larvae collect in a mass which is similar to an inverted cone. Through the centre of this cone they slowly descend until the apex is reached, from which point the ascent is made along the sides of the cone. This collection of larvae takes a well defined relation to the light. The ~~[illegible]~~ jars containing the larvae of [illegible] were exposed to the light of a north window. In the early morning, the cone is in that part of the jar nearest the light. With the increase of light ~~[illegible]~~ the larvae move to the

side of the aquarium farther from the window, the zone is not as pronounced, although the descending and ascending streams of larvae continue. Toward the late afternoon, the conditions were similar to those of the morning. On placing an incandescent lamp near the aquarium at night the larvae invariably collected in that part of the aquarium most distant from the light. By carefully feeding the larvae and changing the water, I was able to secure a series of larvae representing the various stages of development until after they had given up their pelagic existence and settled on the bottom. The metamorphosis occurred in twenty-two days.

In addition to the ~~rearing of larvae~~ larvae which were reared, many were collected by towing. These covered the period from a day old up to twenty two days old, when the larvae are ~~[illegible] [illegible] [illegible]~~ about to settle to the bottom. The latter were reared to later stages in small balanced aquaria. The tow records are significant. At night [illegible] was rarely collected. The larvae become scarce towards the end of July; being most numerous late in June and early in July.

The killing agents employed were Gilson's picro-acetic acid solution, corrosive acetic solution and Petrunkewitsch's fluid. The material was preserved in 50% alcohol. The results were satisfactory.

In the case of the eggs and early larval stages, the material was dehydrated in small sealed tubes of glass and

were about to be infiltrated with paraffin, these boxes were enclosed in [illegible] [illegible]. This small tube prevented the loss of material; ~~while~~ the suspension prevented the rapid cooling of the paraffin during changes. The stages of twenty-four hours and over, the larvae were oriented according to a modification of Patten's Method.[1] In place of the paper suggested by Patten, I made use of that cloth which is used by draftsmen. This can be readily ruled with a needle point.

The eggs for the study of fertilization and cleavage, the eggs were sectioned 3μ and 6μ; larvae and early adult forms were cut 5μ and 8μ. Larvae were sectioned in three planes; (1), perpendicular to the long axis, _transverse_, (2), parallel to the median plane, _longitudinal_, (3), perpendicular to the median plane, _horizontal_. The sections of eggs were stained in on the slide in iron haematoxylin, sometimes counter-stained with eosin, and Flemming's triple stain, safranin, gentian violet and orange G. Sections of the larvae were stained with Mayer's haemalum or iron haematoxylin and eosin. In most cases, the material was previously stained weakly with acid borax-carmine to facilitate the later manipulation. Specimens which were mounted whole, were stained in acid borax-carmine. To preserve the skeletons, the larvae were killed in fresh water and [illegible] quickly dehydrated and mounted. The commonl

---

1. W. Patten ([illegible])

were diluted from absolute alcohol to assure the absence of acid.

The dissection of adults were made upon fresh material or upon that preserved in formalin at Beaufort, N. C. and later studied in the Zoological Laboratory of the John Hopkins University. The histological study of the adult animal was done on material thus preserved. The sections were cut mostly 10μ and stained in acid borax-carmine, iron-haematoxylin and eosin, or saffranin. When acid borax-carmine was employed, the material was stained in toto.

Decalcification was accomplished by immersion in a solution of nitric acid in 70% alcohol. The amount of acid and the time of exposure varied with the amount of decalcification which is required.

In August 1905, Dr. Grave started a balanced aquarium with worms and Echinoderms, but no Phoronis. The sea-water was collected in the outer harbor at Beaufort and no doubt contained larvae of various forms. This aquarium was placed in the Biological Laboratory of the John Hopkins University. In a few months six small Phoronis were observed. These lived until September 1906 when the aquarium "went bad." The sizes of two of these are here given. The last line of figures is the measurements of an individual, which was collected on the

shells, and had attained the growth under [illegible] conditions.

	Length	Width	Depth
Aquarium-------------	3.30 cm	2.15 cm	1.[illegible] cm
	[illegible].07 cm	[illegible].05 cm	1.[illegible] cm
Shell-----------------	2.05 cm	1.84 cm	1.72 cm

The response to the conditions of the aquarium, where, at the greatest depth of the sand, the animals were just covered, is shown by comparing the measurements for depth. The animals which were reared in the aquarium were [illegible] dorso-ventrally.

[illegible]

Moira lives, imbedded in the mud, at a depth of three to eight inches. Figure 1 is a diagram showing the animal in its surroundings. From a tuft of spines on the dorsal surface of the animal there extends to the surface of the sand a tube which is about 5 mm. in diameter. Through the aperture of this tuft of spines, ~~and~~ into the tube, modified tube feet or ambulacral branches extend. The distal end of these ambulacral branches is a disk with a pair of prehensile filaments (Fig. 11. p. f.). [illegible] of the distal portion of the ambulacral branch, [illegible] the surface may be disturbed, and then the prehensile filaments close around the mass. The disk is then withdrawn to the inner portion of the tube where the filaments relax, and the particles of mud

with the attached vegetable matter drops to the bottom, where I am of the opinion that other ambulacral brushes convey ~~it~~ the sand and food to the mouth. I have not observed in young animals kept in aquaria at a depth of a few inches, that the ambulacral brushes convey the food directly to the mouth. However, those I observed upon the shoals behaved in the manner which I have described. These tubes are constructed from beneath the surface, as Figure [illegible] exhibits a number of tubes which had been constructed as the animal moved through the mud.

The action of the ambulacral brushes results in the widening of the upper part of this tube until a funnel-shaped structure is attained. ~~The~~ Funnels range in diameter up to 3 cm, in depth to 2 cm. The ambulacral brushes work from the rim of the funnel inward. ~~The~~ Radiating grooves are in this manner constructed. When the observer walks over the shoal, he notes numerous depressions, shaped like a funnel with these radiating grooves. This is the "sign" of [illegible], and [illegible] one of the presence of the animal. Figure [illegible] is a photograph of the surface of the shoal showing a number of these signs.

[illegible] react to tactile sensations.[1] Stamping on the ground, or even jarring the surface with the palm of the hand within two feet of an external opening [illegible], resulted in the instantaneous withdrawal of the ambulacral brushes.

……………………………………………………………

1. C. [illegible]. (1[illegible]).

changes of light ~~[illegible]~~, such as alternation of intense light and deep shadow were apparently unnoticed..

The animals never come to the surface except when they are forced by adverse conditions. On July 4th, 1902 there was combined a very low tide with intense heat. Numerous Moiras were observed on the shoals and their tests were noted in numbers for several days afterwards. The tide, the lowest of the series, was rendered still lower by local conditions.

Several years later, July 1[illegible], 1905, I observed similar conditions.

The maximum temperature was 90° at Beaufort, N. C. in the protected shelter of the Weather Bureau station.[2] As the slow locomotion of the animals made their rapid progress to the water impossible, numbers were baked by the intense heat. They live in that part of the shoal which is never exposed by the receding tide more than half an hour. The adults move by means of their spines. The ventral part of the test or plastron is furnished with spatula shaped spines which pass the excrement out posteriorly and also help to push the animal forward.

ANATOMY.

Seen from above it is oval in outline, a rounded five sided figure (Fig. [illegible].) Viewed from the left side as in Figure [illegible] the height of the test is slightly less than its length. The posterior ventral corner is rectangular, the others are rounded. In

---

1. Records of the Beaufort Lab. (4).

2. Records U. S. Weather Bureau, Raleigh, N. C.

life the animal is yellowish or straw colored. It is covered with spines, some of which are short. (Figs. 10, 11.). The mouth is situated on the ventral surface about one fourth the distance from the anterior end (Fig. 7 m.). The anus is situated in the posterior interradius, about half way between the dorsal and ventral surface. (Fig. 10 a n.) The highest point of the test, the vertex, is posterior to the median point ~~region~~ (Fig. 8 ver.). Immediately anterior to the vertex is the apical system which comprises the plates bearing the madreporite and genital openings. (Fig. 8, ap. s., 1. mad., 9a)

The ventral surface has a raised plastron, which is composed of the plates of the posterior interradius. (Fig. 7, 9, 10, pl. 1.). The largest individual collected measured [illegible] mm. in length, and 40 mm. in breadth.

The test is fairly thin, averaging .5 mm. in thickness. It is composed of plates which are highest at their middle, sloping to the periphery and bearing knobs to which the spine is attached (Figs. 4,9.) These knobs are arranged in rows. From the apex there extends radially five rows of sunken plates; each series forms deep pockets which project into the cavity of the test. These are the petaloids or sunken ambulacral grooves (Fig. 8 pet.) The anterior unpaired petaloid is the largest, next in order are the anterior paired petaloids; the posterior

petaloids are the smallest. Over these petaloids, the spines of the neighbouring areas project (Fig. 10, 11.). In Hemiaster, the deeper unpaired petaloid of the female serves as a brood chamber; for Moira the same use has been suggested.[1] On this point I cannot add any positive evidence. The tow, however, yields many larvae which from their shape and progress of development agree with those larvae of twenty-four to thirty-six hours which I have reared artificially. The dorsal edges of the anterior unpaired petaloids extend over the sunken portion so as to almost roof the cavity. A similar extension of the posterior border of the anterior paired petaloids almost closes their dorsal opening. (Fig. 6.)

The plates of the radii and interradii are ranged in pairs, not always with regularity (Fig. 5). Within the petaloids, the plates bear two notches to admit the tube feet. Except between a few plates near the apex of the unpaired petaloid, there are thus four parallel rows of tube feet. Near the apex in the unpaired petaloid, each plate bears a single notch.

Surrounding the mouth there is a series of plates which are rectangular in shape; two of these join each ambulacrum groove while one is in contact with each interradius. The plate in connection with the posterior unpaired interradius is

---

[1] A. Lang. (91)

clipped (Fig. 7). Within these, there are a series of smaller movable plates. Surrounding the anus are eight large, rectangular peripheral plates, and within this row a number of smaller plates.

The apical system of plates is immediately anterior to the vertex or highest point of the animal (Fig. 8. ap. s.) Figure 14 is a camera sketch of the seven plates which comprise the apical system. The Roman numerals refer to the radii, the Arabic, to the interradii according to the nomenclature of Lovén.[1] The five radials (r) remain. Each is perforated by a single pore through which the end tentacle of the radial water tube projects. Each of the two remaining plates bears a genital pore (g.o). The pores of the madreporite (mad.) are usually on the right basal, although a few are found on the adjacent area of the left basal. It is apparent that the right basal is the larger. In all the specimens which were examined, this difference was observed. It is evident that the right basal represents more than the basal of interradius, but whether this additional plate is the central plate or the posterior basal, I cannot state, owing to absence of further evidence. Therefore, I have called these two plates, basals. (bs.).

On the denuded test, streaks of apparently smooth surface are found. These are called the semites or fascioles

---

[1] Delage et Hérouard (1903).

(Fig. [illegible],9 Fm.) The peripetalous fasciole extends around the borders of the petaloids. The lateral fasciole passes around the sides of the animal, below the anus, where it becomes a broad band. Anteriorly it crosses the anterior unpaired petaloid at a triangular region, where the sides of the petaloid extend over the cavity. The test is completely covered with spines, which are capable of rapid motion. The spines are for the most part short and shaped like a [illegible]. (Fig. 11). To this there are two exceptions. The spines which form the tuft at the apex (Fig. 11 tt.), and those on the oral side of the test, especially those which are placed anteriorly, are longer and pointed. The spines of the plastron (Fig. 11, pl) have their distal ends flattened; these are shaped like a spade. The spines completely cover the petaloids. The fascioles bear rudimentary spines which are immovable; these are covered with a layer of vibratile membrane. Pedicellaria, usually tridactyl are found on various parts of the test. (Fig. 11 [illegible]).

Figures 11 and 12 show the arrangement of the internal organs. The mouth (o. Fig. 11) is the opening of the oesophagus (oe Fig. 11). This latter is a thin-walled tube which passes posteriorly for about two-thirds of the distance of the test. At this point (s. Figs. 11,12), the oesophagus increases in size to become the stomach, which bends to the right and extends to the caecum (cae.) a distance of [illegible], where the

wall undergoes a decided change; and the digestive tract is now called the intestine(int.A.). This makes a complete circuit of the body wall. This part of the digestive tube possesses thin walls with a folded endothelium and is usually distended with particles of mud which give it a grayish brown color. Anteriorly, at F. 2, it bends on itself and retraces the same area, dorsal to its former position. On the left side, the intestine (Int. B.) does not extend beyond the sunken anterior unpaired petaloid. At this point (F. 3.), there is the final flexure. The diameter of the tube diminishes; this remaining part is the rectum (rec.), which passes in a nearly median position posteriorly until a point above the anus is reached, then the rectum turns sharply downward to the anus (an.). The second part of the intestine (Int. B.) is ~~a~~ light brown in color, has thicker walls and is not usually as distended with sand as is ~~distended with~~ the first part of the intestine. The intestine is held in position by mesenteric strands which are attached to the wall of the test nearest to the tube. The mesenteric strands of the rectum connect it with the stone canal and contiguous parts of the aboral region. The most posterior part of the rectum is supported by the same mesentery (mes.) which serves the axial organs. (A. c. Figs. 11, 12.).

There are, in addition to the digestive tube, two

accessory organ. A caecum (cae) arises from the digestive tube after the latter leaves the oesophagus and before it bends to the left in the anterior region, at which place a decided change in the character of the wall occurs. The caecum is a thin-walled sac which is filled with a colorless liquid. Koehler, according to Hamann, in a paper which is inaccessible to me, reports two accessory intestines or siphons in the genera Echinocardium (sp. ?), Schizaster canaliferus and Brissopsis lyrifera.[1] Later in 1901, Koehler added to this list Schizaster fragilis.[2] In Moira atropos I was able to discover only one accessory intestine. This arises on the dorsal side of the first part of the intestine, which is anterior to the first flexura ~~after making the bend~~ (Pl. I, Fig. 14). In Figure 14, the origin of the siphon (si.) is shown at 1. The siphon (si.) passes to the left, dorsal to the oesophagus (oe) and follows the intestine on its inner side posteriorly until the intestine bends forward, where the siphon enters the intestine at 2.

Figure 15 is a diagrammatic sketch of the digestive organs, as viewed from the ventral side. It is observed that the stomach-intestine bends with the hands of a clock for 540°, then in a reverse direction for 270°; from this point the rectum passes posteriorly in the median plane of the animal.

Figure 17 is a section through the mouth; it passes between the posterior unpaired interradius and anterior unpaired radius. The conditions in both the figures 16 (radius) and

---

1. Hamann (1[illegible]) 2. R. Koehler ([illegible])

the lower lip (intermedius) are similar. The water-vascular ring (w.v.r.) lies next to the coelomic cavity (coel). A tube (b.l.) is attached to the water-vascular ring; the contents of this tube stain deeply in both borax-carmine and eosin. I am of the opinion that this is a blood vessel. The perihaemal cavity (p.h.) is ventral to the water-vascular ring. The walls are thin and are constructed of a single row of cells. The nerve ring (n.r.) is next in order below the perihaemal cavity. The thin-walled epineural (ep.c.) canal ~~with its~~ thin ~~wall~~ is in close union with the nerve ring. In the region marked Upper lip, between the test and the coelomic cavity, there has been cut off a large cavity with thin walls, known as the perioesophagial cavity (p.oe.s.). In the lower lip this also appears. It has pushed its way between the epineural canal and the test. The oesophagus (oe.) is the tube leading away from the mouth. (m).

The water-vascular ring is connected with the stone canal at the point where the right posterior radial water tube leaves the water vascular ring. Accompanied by a blood lacuna it ascends the oesophagus. On the left hand side of the oesophagus is another blood lacuna. The radial water vessels gives off in pairs branches to the tube-feet. Each tube-foot has an ampulla. The sensitive tube-feet, which number twenty-four, encircle the mouth. These bear on their distal ends many minute club-shaped filaments: each filament is

supported by a spine. In the paired petaloids are respiratory tube-feet. These are branched many times, their walls are thin, and devoid of supporting calcareous rods. The ampullae of the respiratory tube-feet are reduced. The most interesting tube-feet are those which are modified for feeding: these are called the ambulacral brushes. They are found in the anterior unpaired petaloid as shown in Figure 10 (am. b.). While they are less than a centimeter in length when retracted, they can be extended to 10 cm. or more. Figure 11 (am. b.) shows a number of these ambulacral brushes: each possesses a large ampulla (amp.). Figure 12 is a camera sketch of the disk of an ambulacral brush, enlarged. The tube and the disk are of a brownish color, the centre of the disk and part of the fimbriae are dotted with maroon, while the latter are tipped with green. The disk is divided into eighteen parts, each of which possesses a calcareous rod (cal. rd.). This rod extends to within a fifth of the distance from the circumference to the centre of the disk, leaving the remainder free to close over the sand which is held fast by the disk. At the same time the rods may incline to each other so that a funnel-shaped structure results. Figure 13 is a camera drawing of a calcareous rod. The rods are perforated in numerous places: the lower central part is a prism. From this base a shaft extends towards the periphery. The perimeter in outline is not composed of a

single filament to each sector as is the case in Spatangus purpureus.[1] ~~It~~ The [illegible] is fimbriated; there are four to six fimbriae to each sector. The ambulacral brush possesses no other skeleton than that indicated by the darker lines in Figure 1.

Moira atropos is dioecious. There is however no sexual dimorphism. The two sexes may be distinguished only by the color of the gonads; the testes are bright yellow, while the ovaries are pinkish. The testes are usually smooth, while the ripe ovaries may appear granulated with the eggs which they contain. There are two gonads. Each gonad has a simple duct which passes through the pore on the basal, or genital plate where it opens through a genital papilla. The gonads are much branched: the finest branches or ul ~~[illegible]~~ unite to form larger branches which join in their turn, and so there are several larger ducts which unite to form the main duct or gonoduct. The germ cells arise from the folded epithelium of the lumen of the finer branches of the gonad. ~~[illegible]~~ In Figure 12, which is drawn from a male, the right gonad is displaced posteriorly to expose the branching of the ducts. When the gonads are immature or spent, they are much diminished in size. The animal from which the sketch, Figure 12, was made was at the height of its sexual maturity for the season. The gonads fill the entire space above the intestine and stomach, and send their branches into the space

---

[1] [illegible] (19)

between the sunken pedicloids.

The readers attention is now directed to the axial sinus which is designated as ax. or. and st. c. in Figures 11 and 12. Its course is that of a curve lying with the legs terminating in the apical and oral regions; the centre of the curve is posterior. As observed in the figures, the sinus lies in the median plane of the animal and passes from the apical system posteriorly, following closely the curve of the posterior interradius, to the wall of which it is attached by the mesentery (mes). In the vicinity of the rectum the axial Sinus bends to the anterior. It passes along the edge of the fold of mesentery on the inner side of the second part of the intestine to the oesophagus (Fig. 12. int. 2.). Then the axial sinus descends to the oral ring, attached by mesentery to the right side of the oesophagus.

The axial sinus contains the stone canal, the axial organs and a blood lacuna. The stone canal (st. c.) commences at the madreporite and occupies a central position in the folds. The calcification extends for less than a centimetre, then the walls become thinner. The stone canal, which occupies the central part of the sinus, passes sidewise into a triangular body which is brown in color and dotted with darker cells. (ax. or.). However, next to the stone canal, there has already arisen a swollen tubular structure with thin walls

which also in its turn passes into this dorsal vascular body. Because of their different content, these two parts of the axial organ appear as separated by a tangential plane which [illegible] that part of the axial organ with thin walls. Figure 18 is from a section made in calcareous region of the stone canal (Fig. 22,18). The stone canal (st.c.) possesses walls of cylindrical flagellated cells which stain deeply. At the side of the stone canal is a sinus (ax. s.) containing the end part of the axial organ (a.o.). Dorsal to this is a blood vascular lacuna (b.l.). The next section, (Fig. 19), is through the commencement of the colorless part of the axial organ. (Fig. 22.19) The stone canal is smaller; its epithelium is however ciliated. The axial organ (ax.o.) occupies most of the cavity of the sinus (ah.). The blood lacuna (b.l.) has increased in size. Figure 20 is from a section near the end of the tangential division mentioned above (Fig. 22. 20.). That part of the axial organ into which the blood lacuna (b. l.) opens begins to decrease in size, while, in the other part of the axial organ (ax.o.) cavities appear. The remainder of the organ consists of thin-walled cavities. Figure 21 is through the part of the axial organ (Fig. 22.20) which is shown in black. The stone canal (st.c.) is beginning to lose its ciliated epithelium; [illegible] [illegible]. Opposite to the stone canal are the remains of the pale portion of the axial organ, which persists in this [illegible] condition.

as blood lacunae (b.l.). The greater part of the axial organ (ax.o.) consists of the lumen and a number of cavities. These cavities have a thin epithelial layer. They are separated by a homogeneous connective tissue which takes stain readily. These cavities contain free cells and granules which vary in size and stain deeply in either iron-haematoxylin or saffranin. Some of the granules are also in the lumen. Some of the cavities connect with the lumen and with each other; these tubes are longitudinal, of considerable length, and extend~~ing~~ through the axial organ in communication with other cavities and, directly or indirectly, with the lumen. Figure [illegible] is from a section near the junction with the oesophagus. (Fig. [illegible]). The lumen continues, There is also the water tube (st.c) and the blood lacunae. (b.l.). The lumen disappears in the lacunae. ~~and~~ As stated above, the water tube and blood tube pass along the right side of the oesophagus to which they are attached by mesentery. At the junction of the radial water canal of the right posterior paired radius with the ring canal the stone canal enters the ring canal.

The material from which these sections were made, was not well preserved. As it is my purpose ~~[illegible]~~ to investigate this rather more carefully at the first opportunity, I shall not enter on a discussion of the physiological importance of the various

parts of the axial organ.

FERTILIZATION AND SEGMENTATION.

The ~~[illegible]~~ unripe egg is large and colorless, it is eighty-two microns in diameter. The germinal vesicle (g. v.) Fig. 26) occupies nearly two-thirds of the length. However, it is slightly swollen owing to the presence of sea-water. The germinal vesicle is eccentric, and contains a single nucleolus. In eggs which are preserved in corrosive-acetic solution the cytoplasm appears to radiate from the periphery of the germinal vesicle to the periphery of the egg.

Maturation occurs before extrusion. The egg-nucleus which occupies a central position is only one-seventieth of the contents of the entire egg. It is highly refractive body. Preserved material shows the chromatin arranged in a reticulum. ? There is no sign of a nucleolus.? Polar bodies were found adhering to only a few eggs. When the eggs are released from the ovary they are usually irregular in outline; this irregularity is due to the close segregation of the eggs within the ovary. They become spherical either immediately after liberation or after the entrance of the sperm.

The fertilization membrane or vitelline membrane is thrown off within twenty seconds after the first attack of the sperm. The head and middle piece alone enter the entrance cone. The course of the sperm within the egg can be

~~usually~~ readily observed, first on account of its refractibility, and later by the sperm aster which forms in the cytoplasm. The female pronucleus makes slight if any move toward the advancing male pronucleus. I have observed the pronuclei, in juxtaposition as early as five minutes after the entrance of the sperm. ~~By nine minutes~~, ~~however~~, In all eggs where fertilization will be effected, the two pronuclei are into contact nine minutes after fertilization.

Preserved material of this period gives more detail of these phenomena. Figure [illegible] (1 minute after addition of sperm) shows the vitelline membrane (f. m.) the entrance cone (e. c.), the sperm head (s. h.) and the entrance funnel (e.f.) The axis of the sperm head is perpendicular to the tangential plane drawn through the point of entrance. Figure [illegible] ([illegible] min. after fertilization) shows the sperm head (s. h.) as having accomplished 90° of its rotation. The division of the sperm into sperm head (s.n.) and middle piece (m.p.) is distinguishable. The entrance funnel (e.f.) is that part of the cytoplasm between the sperm nucleus and the entrance cone; the cytoplasm in this space stains with less intensity than that of the surrounding area. There is no sperm aster at this stage. By the time rotation is complete, the sperm aster appears. I have observed in some specimens of this period that the cytoplasm of the area where the aster is to appear is less granular and stains deeply. As the male pronucleus with its attendant

early advancing towards the female pronucleus it loses its compactness, and becomes vesicular with its chromatic material arranged as a reticulum. Figure 7 gives the normal condition nine minutes after fertilization. The male pronucleus is the smaller. Its vesicular character is apparent and as stated above the nucleus takes on this character in it's advance towards the female pronucleus. The centrosomes have divided and the daughter centrosomes have separated. The sperm aster (s.a.) has, conformably to these changes, also separated.

In the living egg the male and female pronuclei have been distinguished as highly refractive bodies. About eleven minutes after fertilization this refractibility begins to decrease until at thirteen minutes the nuclear area can only be observed as hyaline. The astral rays have been penetrating nearly to the circumference of the egg. For about four minute the only change to be observed is the reduction of the astral system. Then changes appear with great rapidity. In the hyaline region, there appears a sharply defined and highly refractive elliptical nucleus. At eighteen minutes after fertilization at each end of the long axis of this ellipse a clear circular area appears. From these as centres short astral rays diverge. These centrospheres increase in size and move away into the cytoplasm. The sharp limiting boundary of the nucleus disappears and fibres from the centrospheres

penetrate the nuclear region, and thus, a double system is established. Each centrosphere also establishes an amphiaster. These are the conditions about twenty-seven minutes (which I should name as the metaphase stage of the first cleavage.

Figure 26 is drawn from a section of an egg of the twelve minute period. The two nuclei are apparently one. The wall between the pronuclei has disappeared and the chromatic contents of the male pronuclei can be distinguished in the upper part of the nuclei, as the reticulum is there more compact. The centrosphere has a small astral system, ~~however~~, In addition to this, on one side of the egg nucleus are rays which extend into the cytoplasm. Three minutes later, which is the next period which was studied, no difference can be observed in the chromatic contents of the egg nucleus. The nucleus has enlarged, and the reticulum has become more open, the membrane is present but appears as though attempting to accommodate itself to the enlargement of the nucleus. It is at this period in the living egg that the nuclear area can be distinguished only as an invisible area. In figure 28 (18 min.), the membrane is clearly defined. The two centrospheres have withdrawn into the cytoplasm at a point opposite the egg nucleus. The spireme is formed from the reticulum breaking up into chromosomes. In figure 29 (21 min.), the chromosomes are arranged in the equatorial plate. The fibres of the

spindle stain more easily than the astral rays. The centrosphere is a vesicular structure resembling ~~in structure~~ the white of an egg when beaten. The astral system is limited, as compared with that which was observed during the pause between the union of the two pronuclei and the apparent commencement of the cleavage process. The entire spindle and astral systems ~~is~~ are in appearance less granular than that comprising the major contents of the egg.

In a living egg which was previously the indentation of the lines which marked the commencement of the cleavage of the cell was observed thirty three minutes after fertilization. The spindle, the amphiasters and the centrospheres were clearly marked. This same egg completed its cleavage plane three minutes later. The daughter nuclei had formed and appeared as highly refractive bodies, one in each cell. The remains of the amphiasters and spindle were yet clearly visible, and the spindle fibres were observable in every case until the completion of the cleavage.

The study of preserved material proved that normally the first cleavage is not usually accomplished until forty two to forty five minutes after fertilization. Figure [illegible] ([illegible] min.) shows the beginning of anaphase, the chromosomes are beginning to draw away from each other. (Figure [illegible] ([illegible] min.) is a later

many arms. This sketch is from 5 μ section μ in thickness, and so is simply an optical section. The fibres of the centrosphere appear to be continuous with the granules of the cytoplasm. Figure 23 is a sketch from a 5 μ section of a precocious egg, thirty-nine minutes after fertilization. This condition is normally found at forty-five minutes. The daughter nuclei have been formed. The chromatin is again arranged as a reticulum. The centrospheres contain two centrosomes. The new spindles ~~[illegible]~~ form rapidly so that at fifty-one minutes after fertilization there are many eggs where the mitotic figure of the second cleavage is in metaphase. Figure 24 shows this condition. Owing to the destruction of one cell, one figure alone appears. This is in metaphase. The centrospheres have the same vesicular structure as observed in the first mitosis.

The cleavage of Moira ~~is~~ proceeds rapidly ~~effected~~; the first cleavage is complete in forty-two minutes, the second cleavage in sixty minutes. The following comparison can be drawn between the rapidity of the cleavage processes in Moira atropos and Toxopneustes variegatus which latter E. B. Wilson records[1]:

	Moira	Toxopneustes
Sperm aster at margin	5 min	7 min
First contact	6	8
Nuclei fusing	[illegible]	[illegible]
Pause	[illegible]	[illegible]
Early stages	[illegible]	[illegible]
Prophase	[illegible]	[illegible]
Metaphase	[illegible]	[illegible]
Cleavage	[illegible]	

---

1. Wilson (39)

Attention should also be drawn to the fact that the sperm nucleus assumes a reticular structure on its advance to the female pronucleus. Moreover, the phase is of much shorter duration than in Toxopneustes. Between the commencement of the union of the nuclei and the early stages of mitosis there is only six minutes as against twenty in Toxopneustes. The figures I quote for Moira were invariable in every observation made ~~in~~ upon the living egg, and ~~is~~ they are confirmed by the study of preserved material.

THE FIRST TWENTY-FOUR HOURS.

The larvae of echinoids were styled plutei by Johannes Müller, owing to a so-called similarity to an artist's easel. MacBride suggests the use of echinopluteus.[1] I choose to use the term larvae to indicate the embryonic stages of Moira, ~~as~~ so long as locomotion is accomplished by means of cilia.

As stated above, the first cleavage is completed forty-five minutes after fertilization, the second cleavage, sixty minutes. Figure [illegible] is a figure of a four-cell stage. The cells are not spherical but are adapting themselves to their juxtaposed condition. The eight-cell stage follows this within twenty minutes. In fact one of the striking things in the development of Moira is the rapidity of its development. Figure [illegible] is a sketch of a twelve-cell stage. The micromeres

---

[1] MacBride (54)

(mi.) have been budded off from the lower tier of the eight-cell stage. Thus the vegetative pole is defined. Figure 37 is a sketch of transverse section through an egg of the sixteen-cell stage. Four of the lower tier of eight cells, two of the middle tier of four cells and three micromeres (mic) are to be seen. The cleavage cavity (c.c.) is the cavity contained within these cells. Although the rudiment of this is apparent in the eight-cell stage, it is not sharply defined, until this latter, the sixteen-cell stage, is reached. In Figure 38 the cleavage cavity (c.c.) is more sharply defined. This is a drawing of an oblique section of a thirty-two cell stage.

Three hours after fertilization, a sphere of many cells, the blastula stage, is formed. Figure 39 is from a longitudinal section of a blastula, three hours old. The cleavage cavity (c.c.) is now quite large and is surrounded by a continuous wall of cells. The cells of the vegetative pole, which have been derived from the micromeres (m. c.) are elongated, and apparently have not suffered as much division as the others. In this section one cell is in process of division. In other sections of this same larva, more division is taking place. A majority of cells are resting, and there is no longer that uniformity of division which characterizes the

earlier stages of segmentation. The flagella become bullet shaped. The cells acquire cilia, and rotation within the membrane commences. After liberation from the fertilization membrane, the larvae swim on the bottom of the bowl. About seven hours after fertilization the larvae begin to make their way to the surface of the dish, and by nine hours, those which are [illegible] successfully reached the [illegible] [illegible] in [illegible] cells motion at the surface of the water, on that side of the bowl, which is nearest the window. The movements of the larvae are a forward translatory movement, and a rotation in the direction of the hands of a clock. Figure 20 is a longitudinal section of a larva, six hours old. The bullet-shape is evident. The cells of the vegetative pole, which have been derived from the macromeres are commencing to bud off cells which protrude into the cleavage cavity. Some of these cells, called mesenchyme (mes.) wander into the cleavage cavity, others remain attached, and as these cells are budded in numbers, they usually appear as a mound with its base in the vegetative pole.

Figure 21 is from a longitudinal section of a larva, nine hours old. The mesenchyme cells (mes.) are in some instances either directly, or indirectly by means of protoplasmic strands, attached to the walls of the larvae and thus function as muscles. (mus.). There is visible also an invagination (ar.ch.) at the vegetative pole. The entoderm invaginateS into the

cleavage cavity (c.c.); and there is formed a small finger-like pocket, the rudiment of the archenteron. The opening of the archenteron (a.ent.) is the blastopore (bl.) which persists as the larval anus. This period of larval development is called the gastrula-stage. The cells at the animal pole are becoming more cylindrical, to become the apical plate of the later larvae. The shape of the larva now changes. One side becomes flattened and from the corners of the vegetative region projections form, so that the larvae is now similar to ~~the echinoderm type~~ an echinoid pluteus. Figure 42 is an optical section of a whole mount of a larva, twelve hours old. One corner shows one of the projections which is described above. The archentron (a.ent.) is now larger, as the invagination extends nearly to the animal pole. The cells at the animal pole have increased in size longitudinally, so that there can be distinguished a definite region of cylindrical cells which are longer than those of the remaining ectoderm. This is the apical (ap.). plate. The cells surrounding the archentron which have originated from the invaginated cells of the vegetative pole shall now be termed endoblast. In the cleavage cavity (c.c.) are many mesenchyme cells. (mes.) The apical plate is anterior; the side containing the blastopore or larval anus is ventral. Thus, the larva, shall henceforth be oriented.

The skeletal system develops from five centres. In

either side, two initial spicules are quite close. Figure 68 gives the skeleton between fifteen and twenty hours old. On each side, a triradiate spicule has given rise to three rods which I shall call the postero-dorsal skeleton (pd. s.), one extends posteriorly, the second extends ventrally towards the anus, the third extends into the rudiments of the first pair of arm. This latter rod is similar to a ladder, except that on its ~~the~~ ventral side, the rounds are attached to a third curved rod. Near the skeleton of the postero-dorsal arm a second, also triradiate, is found: this is the antero-lateral skeleton. (a. l. s.). The spine which projects anteriorly will become the skeleton rod of the second pair of ciliated arms which arises from the pre-oral lobe. In the posterior region is another skeletal structure which is unpaired (v.p.s.). This has two lateral spines which extend towards the posterior spine of the postero-dorsal skeleton, one sp which extends anteriorly, and three spines which extend posteriorly. Of the latter, ~~which~~ at this time, only two are developed. These latter form a ladder wh similar to that above mentioned and which is the support of the posterior unpaired arm which passes out from this point.

A pouch developed at the tip of the archenteron. This pouch is then pinched off to form a closed sac, the enterocoelomic cavity. Figure 69 is from an oblique section of an egg sixteen hours old. Above the enterocoelomic cavity (en. co.) is the apical plate. (a.p.). Then a group of a great number

of sections, I am inclined to believe that this cavity, the enterocoelic cavity, is first pinched off from the archenteron, and then divided into two elongated sacs which are placed one on each side of the enteron (ent.); as the remaining part of the archenteron is now called. Figure 40 shows this latter condition. The enteron, through changes in shape of the larva, is now L shaped, as the anus is on the flat ventral face of the larva (Fig. 45). This section (Fig. 40) is through the apical plate (ap.) and the long arm of the L (ent.). The enterocoelic pouches are on each side of the enteron (ent.).

Figure 44 is from a longitudinal section through a larva twenty-two hours old. The posterior surface of the gastrula has developed a long unpaired arm which is characteristic of spatangoid larvae. The enteron is divided by constrictions into an oesophagus (oe.), stomach (st.), and an intestine. (int.). The intestine (int.) opens to the exterior through the anus (an.), as the blastopore is now called. The apical plate (ap.) extends towards the ventral side of the larva to form the oral lobe. On the same side as the anus and anterior to the apical plate, is an ectodermal invagination which becomes the larval stomodaeum (l.st.). This is seen in contact with the anterior part of the oesophagus but has not broken through. The orientation is also indicated in this figure [illegible].

Figure 40 is a larva twenty-four hours old. The postero-dorsal arms (p.d.) are those whose rudiments are first developed. They extend laterally and anteriorly from the middle of the larva. They acquire [illegible] extend posteriorly. The oral region is developing into a hood, the praeoral lobe (p.o.l.), which is a ventral extension anterior to the mouth ~~opening~~ (m.). The cilia (l.b.) extend in a loop before the praeoral lobe, and then posteriorly along ~~its~~ the sides ~~of~~ of the larva to the postero-dorsal arm, ~~to the [illegible] which it extends~~, The ciliated band (l.b.) passes to the apex of the arm and then down on the ventral side. ~~and across~~ It crosses the postoral lobe (p.l.) ~~to~~ and returns to the edge of the praeoral lobe in a reversed direction. The digestive tract can be seen within. In the anterior corner of the mouth and extending into the oesophagus to meet its fellow of the opposite side is a ciliated band. (c.b.). ~~The~~ One enterocoelomic cavity (en. co.) ~~lies~~ is ~~on~~ on each side of the oesophagus. Figure 49 is composed of two sections so as to approximate a median horizontal section. The age of this is twenty-six hours.

FURTHER DEVELOPMENT OF THE ENTEROCOELOMIC CAVITIES.

The coelomic cavities have lengthened so that they now extend past the oesophageal-gastric connection and on to the side of the stomach. Thus far there has no connection been established between the dorsal ectoderm and the oesophagus. Each enterocoelomic cavity begins to separate opposite the constriction of the oesophagus, into an anterior and a posterior coelom. ~~into an anterior and posterior~~

coelom. The lower portion of the left anterior coelom, which is yet connected with the left posterior coelom, enlarges; this enlargement is the ampulla. From the dorsal wall of the ampulla a tube is evaginated, ~~which~~ This tube grows [illegible] to the [illegible] (toward the middle line), where it is pressed against the body wall of the larva. ~~This~~ Tube opens to the exterior ~~at this point~~ in the median dorsal plane. This dorsal opening is the dorsal pore; the tube is the pore canal. Figure 60 gives the result of the phenomena described above. This drawing is from a transverse section of a larva forty-eight hours old. The ampulla (am.) lies opposite the anterior region of the stomach. The pore canal (p.ca.) is the thin-walled tube which passes from the dorsal part of the ampulla (am.) to the dorsal wall of the larva.

Along with these changes the larva is undergoing external changes. Figure 61 represents a larva seventy-six hours old. The first pair of arms, the postero-dorsal (p.d.) have lengthened. The second pair of arms are the postero-lateral arm (p.l'), which are found on the [illegible] dorsal edge of the lateral [illegible]. (p.l.) ~~They~~ antero-lateral arms commenced as small knobs when the larva was thirty-six hours old, and developed rapidly, carrying with them, as do all the paired arms the longitudinal ciliated band. (l.c.b.). The postoral (p.o.) arms, which are next formed, lie dorsal to the antero-~~lateral~~ dorsal arms in the same transverse plane.

between the bases of these posterior paired arms, are slightly epaulets thickened. The last pair of arms, the preoral arms (p.a.) are represented by small knobs on the ventral border of the preoral lobe. (po.l.). The unpaired anterior arm (a.) is well developed. Throughout the larva and its epidermis there are numerous pigmented granules (gr.). The pigment is invariably of a maroon color. Mac Bride observed in Echinus esculentus and Echinus miliaris that these pigmented bodies were either imbedded in the ectoderm or were contained in amoebocytes which were migrating outward. I was able to confirm the former observation. It is concluded that these bodies are excretory material in the process of removal.

Figure 52 is a reconstruction of a series of transverse sections of a larva seventy-two hours old. Only the left side is shown, as the right consists of two coelomic cavities which have not been differentiated. The left anterior coelom has given rise to four structures. Anteriorly and extending along the oesophagus is a cavity which is shaped like a pointed pyramid towards the apical region. (l. a. c.). Posteriorly this enlarges to become the ampulla (am.). The pore canal (l.p.c.) leaves the ampulla on its dorsal surface and leads to the exterior through the dorsal pore. (d.p.). The remainder of the hydrocoele (l.hyd.) comprises the posterior region of the

………………………………………………………………

1. Mac Bride [illegible]

left anterior coelom. It is seen in contact with the left posterior coelom (l.p.c.) which is extending posteriorly parallel to the long axis of the embryo. Between the hydrocoele and the ampulla there is a short connecting tube. This is the rudiment of the stone canal. (st.c.). In this larva there was on the left side between the bases of the antero-lateral and postoral arms an ectodermal invagination, the echinoid pouch, the bottom of which was nearly in contact with the rudiment of the hydrocoele.

Figure 30 is a [illegible] larva, six days old, which is drawn to show ~~chiefly~~ the skeleton and the stomach contents. The larva has now attained its complete larval form. The last pair of arms, the pre-oral arms are formed. The arms are of such a length that their tips are in a plane perpendicular to the long axis of the larva. The only difference I have been able to discover between the larvae I have reared in aquaria and those which have been taken in the field is an increase in the lengths of the arms of the latter. The skeletal rods of the postoral arm, of the postero-dorsal arms and of the antero-lateral arms increases in length with the growth of these arms. That part of the skeleton which projects into the anterolateral arm is a single rod in contrast to the ladder like structures of the postoral arms. Dorsal to the centre of the ossification of the skeleton rod of the antero-lateral arm, the skeleton of the preoral arm

modified into a trifurcate structure. That part which extends into the arm is ladder-like in construction, the posterior rod and the dorsal rod, which bifurcates, are simple rods. Thus there is developed along the same line, dorso-laterally, the skeletal rods of three types of arms. For a time these are independent, but in a larva in the fifteenth day it is noted that the bases of these three systems, together with a projection from the skeletal process of the unpaired arm, are closely interlaced by branching and anastomosing processes. (Fig. 54) The skeleton of the praeoral arm arises in the dorsal region of the embryo near the cardiac end of the oesophagus. It is U shaped with a small rod projecting posteriorly from the bend of the U. Each leg of the U is a simple rod which projects into one of the praeoral arms. The pigmented spots are more numerous. The tips of the arms are solidly colored. The stomach is usually pigmented brown with a corner of green. This is due to the character of the food, diatoms and algae. In Figure 55 a number of diatoms are contained in the stomach.

As stated above, each process sends a rod to the posterior region of the larva. In 1900, Grave described for "Ophiura brevispina" four sphincter muscles connected by tendons with the ends of these rods.[1] Thus is accounted for the lateral movements of the arms, and further is inferred from the relation

---

[1] C. Grave (1900)

of these muscles to the stomach and intestine, their function in forcing the contents of the intestine out through the anus by acting as sphincters. Figure 5 shows a similar condition for Ophiura and my own observations confirm those of Grave. The ends of the four skeletal rods (rds.) are attached to each other by four muscles (sph.). The muscles are united with the rods by tendons (tend.). The contraction of the sphincters closes the gastric-intestinal aperture, while the consequent movement of the posterior dorsal rods towards each other compresses the intestine. ~~and~~ Thus, the excreta ~~is~~ are forced through the anus. Beside the movement of the arms and digestive tract which has been noted, there can be observed the withdrawal of the edge of the postoral lobe and, also peristaltic movements of the oesophagus. These are due to muscular bands. In the preoral lobe there is a median series which joins the dorsal border to the ventral border. Laterally, the musculature extends from the border either to the rod or to the vicinity of the rod supporting the preoral arm. The musculature of the postoral lobe extends from its sides to the skeleton rod of the postero-dorsal arm. The contraction of these muscles retracts that portion of the ciliated band in which it is inserted. The oesophagus is surrounded by a transverse musculature which produces a peristaltic movement by which is swallowed the material swept into the mouth by the ciliated oral band.

The right enterocoelic pouch divides into an anterior and a posterior cavity. Then a differentiation similar to that of the left side occurs. Figure 56 is a reconstruction of a five day larva to show the right side. If examined in connection with Figure 55 the homology between the right and the left side is striking. The right pore canal (r.p.ca.) [illegible] dorsally. In later stages it meets and opens with the left pore canal, ventral to the dorsal pore. In contrast with the right posterior coelom (r.p.c.) in the posterior region of the right anterior coelom (r.a.c.) which is similar in form to the left hydrocoele of the [illegible] period. The [illegible] described for A. [illegible] a structure which separates from the right anterior coelom and remains as a closed vesicle near the left pore canal throughout the entire life of the individual. As far as my studies go, which is up to the settling time of the larva, the right anterior coelom is always in communication with the left pore canal by its outgrowth, while I [illegible] the right [illegible].

The left hydrocoele, as stated above, is derived from the posterior region of the left anterior coelom. Its [illegible] are [illegible], and in this it differs from [illegible] part of the left anterior coelom [illegible] the [illegible]. These [illegible] are [illegible] and a few [illegible]. The [illegible]

---

1. [illegible] (18[illegible])

ventrally to make a portion of the left anterior region of the stomach. It also assumes the form of a ring. The process by which this is effected is illustrated by reconstructions, figures of which will be described below. Bury stated in 1889 that the transition from the closed vesicle of the rudiment of the hydrocoele to the water-vascular ring was through a horse-shoe shaped stage with the legs pointing posteriorly.¹ The free legs of the structure were finally joined, and the ring completed. Grave in 1902 recorded in Ophiura brevispina the hydrocoele as forming an oval loop with the opening towards the ventral side.² This finally closes as the end grows anteriorly to meet the rudiment of the hydrocoele. Theel in a paper which is inaccessible to me, but which is summarized by MacBride asserts that in Ophiura ciliaris the hydrocoele is at first a semicircular disc.³ On the border of this disc a notch appears. The edges of this notch meet and the ring form is attained. Figure 20 is a reconstruction of the left side of a larva of ten days. The echinoid pouch has been omitted. The hydrocoele (l.hy.) has assumed the shape of an inverted U, which opens posteriorly. On the outer border of the stone canal(st.c.) are two prominences (t,t). These are the rudiments of the primary tube feet. The left posterior coelom (l.p.c.) extends to the posterior region of the larva. It is nearly

....

1. H. Bury (5) 2. C. Grave (27) 3. E. W. MacBride (52)

indented by an embayment on the ventral side. Figure 58 is a similar reconstruction of a larva, nineteen days old, but when I compared it with other larvae, I was inclined to place its age at about sixteen days. The ring form is complete. The rudiments of the five primary tube feet (I,II,III,IV,V) have appeared. From a study of a number of reconstructions, I find that the U is united between those rudiments of the primary tube feet, which I have designated as II and III; that is, the legs of the U form the rudiments of two primary tube feet (II,III). The left posterior coelom has likewise formed an opening which finally comes to be immediately beneath the opening of the ring of the hydrocoele. This opening is formed by the closing of the embayment which was observed in figure 57. Both anterior and posterior edges grow and meet enclosing this space. The left posterior coelom is extending to the median plane of the larva.

On the right side, the right posterior coelom is also spreading over the walls of the stomach and intestine. The posterior region of the right anterior coelom in the same reconstruction was observed to be an expanded vesicle flattened against the right posterior coelom. The right pore canal, as stated above, bends around the dorsal wall of the esophagus, to meet the left pore canal. Figure 59 is a reconstruction of the dorsal part of larva, fourteen days old, the region [illegible] is in the vicinity of the [illegible] [illegible].

The two pore canals are seen with a single median opening. It is observed that the right pore canal opens into that leading from the left anterior coelom. I have described in 1906 two similar pore canals in E. testudinaria.

Figure [illegible] is a transverse section of a fourteen day larva through the lower part of the oesophagus (oe.). In this section the dorsal pore is not shown. On the right is the anterior coelom (r.a.c.), with the right pore canal (r.p.c.) leading dorsally. The right pore canal meets the left pore canal (l.p.ca) ~~which meets~~ in another section, which is posterior to this section, ~~the left pore canal (l.p.ca.)~~. This canal arises in the ampulla (amp.), the walls of which are thin and the nuclei scattered. The hydrocoele (hyd.) is beneath the mass of cells (ech.d.) which is the wall of the echinoid sac or amniotic cavity. The hydrocoele (l.hyd.) is connected with the ampulla (amp.) by a short tube, the stone canal (st.c.), which is formed as the hydrocoele grows away from the ampulla. The right posterior coelom (r.p.c.) and the left posterior coelom (l.p.c.) are found on each side of the stomach.

I was able to confirm MacBride's observations on the apical nervous system of E. esculentus.[2] In larvae of five days, there is found at the apex of the praeoral lobe a thickening of the ectodermal epithelium. From the cells of this thickening (Fig. [illegible] a.p.) nerve fibrils extend. These are found running from right to left, and in the illustration their cut ends (n.f.) are observed beneath the ectodermal thickening. The apical plate which has been mentioned by some writers is not present in

---

1. C. Grave (17)   2. E. W. MacBride ([illegible])

well developed in [illegible], where it is composed of long columnar ectoderm. However, in connection with it I was unable to describe any visible or other evidence of nervous tissue. As pointed out by MacBride, this structure becomes part of the ventral border of the [illegible] lobe.

DEVELOPMENT OF THE [illegible] STRUCTURE.

The echinoid pouch forms as an invagination of the lateral border of the larva between the bases of the postero-dorsal and postoral arms. This increases in size and comes in contact with the hydrocoele. The base enlarges while the aperture constricts so that the structure is similar to a flask. The echinoid pouch increases until there is formed over the hydrocoele a large sac, which opens to the exterior by a small pore. The cavity of the echinoid pouch will hereafter be called the amniotic cavity. The floor of this cavity, which is in contact with the hydrocoele, thickens while the roof is drawn out so as to consist of a thin layer of tissue with scattered nuclei. On the floor of the amniotic cavity ~~there arise~~ five radiating thickenings are formed. These correspond in position to the future interradii. Figure 31 is a transverse section through a larva of fourteen days old. The 5 rayed structure on the floor of the amniotic cavity (amn.c.) is derived from the ridges above mentioned. At their outer ends these ridges fold laterally (am.f.). These lateral foldings [illegible] and so there is formed within the amniotic cavity another cavity which is confined within these ridges and roofed by their overhanging edges. This [illegible] consists of

five arms, in the future (ap.), and a central space. Figure 61 also shows the hydrocoele (hyd.), the ampulla (amp) and part of the pore canal (hyd.ca.). The left posterior coelom (l.p.c.) is ventral to the hydrocoele and at this period has not extended beneath it. Figure 62 is a section showing the origin of those pouches which are the rudiments of the lantern apparatus in those echinoids which are possessed of a masticatory apparatus. The dental sac, as I shall call it to preserve the analogy, arises as an evagination of the left posterior coelom in the five interradii, close to the hydrocoele ring. Their position is shown in figure 66 which is a reconstruction of a larva, 14 days old. The dental sac (d.s.) is placed, between a part of the rudiment of the radial water canals numbered II and III. (Fig. 63). At this stage, these radial water canals are ~~merely~~ the primary unpaired tube feet. Its wall is of a thickened epithelium. The dorsal pore (d.p.) is clearly shown. Above the radial water tube III, the cells of the ectodermal floor are made up of long cylindrical cells. These cells will become the radial nerve (n.3).

To observe the further development of these structures, the origin of those rudiments have been traced, it will be well to examine several sections of a larva which would have soon settled to the bottom.

Figure 64 is that a transverse section through the oesophageal-gastric junction and anterior to the hydrocoele ring and also through the anus (a.). The right posterior (r.p.c.)

coelom is a thin cavity with thin walls; anteriorly it extends along the oesophagus to the posterior border of the right anterior coelom; posteriorly it reaches nearly to the base of the unmodified arm. The right pore canal (r.p.ca.) which communicates with the right anterior coelom is observed in communication with the left pore canal (l.p.ca.), as was brought out in a reconstruction of larva of an earlier stage. (Fig. 56.). The dorsal pore (d.p.) ~~is~~ is the aperture by which the left pore canal (l.p.ca.) opens to the exterior. The left posterior coelom (l.p.c.) occupies a more extensive position than the right posterior coelom. Throughout most of its extent, as may be observed, the coelomic epithelium is a thin membrane with scattered nuclei. However, in the dorsal part of the section the nuclei are more closely grouped. Between the left posterior coelom and the digestive tube and at the base of this modified dorsal part of the left posterior coelom is a small round cavity, the stone canal (st.c.). The left posterior coelom lies between the stone canal and the radial water tube (r.w.) which in the notation I have adopted is V. The radial nerve, (r.n.) lies above the radial water vessel. The radial nerve consists of a core of nerve fibrils, surrounded by many cells, whose nuclei stain deeply. A number of the nerve fibrils can be traced to cells in this section. The epineural cavity (ep.c.) surrounds the radial nerve. It is thus perceived that the nerve arises as a thickening of a portion of the

tube, and as the nerve increases in size, the epineural cavity must decrease. The epineural fold (ep.f.) lies between the epineural cavity (ep.c.) and the amniotic cavity (amn.) which is the cavity of the original ectodermal invagination. The primary tube-foot (t.f.) of what will be the extremity of the radial water tube IV ~~lies~~ is above the genital region of the left posterior coelom (l.p.c.)

Figure 55 is a transverse section through the same larva, thirty-six microns posterior to the section drawn in Figure 54. This section passes through the hydrocoele ring, in the region of the adult mouth. The epithelium of the stomach is ciliated. The hydrocoele ring (l.hyd.) lies above the stomach. The hydrocoele ring has enlarged somewhat out of proportion to growth. The opening of the ring is reduced, so that in this section it is observed as two adjacent parallel strands of tissue. The nerve ring (n.r.) is observed to the left of the hydrocoele. The adult stomodeum (ad.s.) has appeared as an invagination of the ectoderm of the future echinoderm, and lies between the two parts of the nerve ring. Between each nerve ring and the corresponding hydrocoele cavity is a cavity. The dorsal cavity ~~of these two cavities~~ is connected with a dental sac (d.s.). These cavities are parts of the perihaemal ring (p.h.). They arise from the dental sacs. After these sacs are constricted off from the left posterior coelom, their inner sides push in between the nerve ring and the hydrocoele ring. These invaginations do not fuse, but remain as five [illegible] cavities, between the nerve ring and the

hydrocoele ring. Thus there are four rings illustrated in this figure, the hydrocoele or water vascular ring, the perihaemal ring of five separate cavities, the nerve ring, and the epineural ring. On the ventral side of the ring is another dental sac (d.s. but this section does not pass through its connection with its corresponding cavity.

Figure 66 shows the same condition for a larva of later stage. The dental sac (d.s.) has pushed its way through the ectoderm and in reconstruction the five sacs appear as finger like projections around the mouth. Three of the perihaemal cavities are sectioned (p.h.). The other structure are similar to Figure 65. The hydrocoele ring (l.hyd.) contains many wandering cells. This section passes through an interradius and a radius. ~~this~~ In the interradius is ~~contains~~ a dental sac (d.s.). ~~and a radius.~~ The radial nerve (r.n.) with the long strand of nerve fibrils is seen arising in the ventral side above the hydrocoele.

Figure 67 is a section through the anterior region of a larva after losing its arms. The section passes through the commencement of the hydrocoele ring. The stomach (st) shows that change known as histolysis. The cavity becomes narrower and the whole digestive tract instead of being two large cavities as in the larva, is now narrowed to a tube surrounded by walls of the two posterior coeloms which enlarge to meet these new conditions. The walls of the digestive tube are also thicker and folded.

The stone canal (st.c.) is shown in part, while the connection with the dorsal pore (d.p.) is here indicated by a dotted line. The two radial nerves (r. n. 4 and r.n.5.) of the radii IV and V are shown. Between them is a perihaemal cavity (p.c.). A radial water vessel (r.w.v.IV and r.w.v.V.) is beside each nerve. Beneath these structures is the wall of the hydrocoele ring (l.[illegible])

Before the larva gives up its pelagic habit it becomes unsymmetrical by reason of the echinoid on its left side. The tube feet and spines break through the thin roof of the am~~m~~niotic cavity. Then the ciliated band diminishes and the larva slowly sinks to the bottom and locomotion is ~~effected~~ brought about by the tube-feet and the spines. Externally, the changes at this time are rapid. The arms disappear after they are carried as useless impediments for a day or so. The outline, which is at first regular, becomes elliptical. Figures 18 and 19 are from a young adult at this time. The lip of the plastron is formed (l.p.). Surrounding the mouth are five tentacles, which are placed interradially. These are the dental sacs. (d.s.). In the radii are tube feet. The unpaired tube feet appear as papillae on the dorsal surface at the tips of the radii. The spines are mounted on knobs and through the thin epidermis the muscles, which move them, are visible.

SUMMARY.

Subsequent to the gastrula stage, the important changes are as follows. The coelomic pouch or enterocoele separates from the archenteron before dividing into right and left enterocoeles.

each enterocoele separates to form an anterior and a posterior coelom. The right anterior coelom, after it has separated from the right posterior coelom, undergoes no further division but sends out a tubular process, the right pore canal, which fuses with a similar process of the left side, the left pore canal, and the latter opens to the exterior by the dorsal pore or madreporite. The left coelom separates into an anterior portion and a posterior portion. The left posterior coelom becomes ring shaped. The left anterior coelom enlarges in its middle region and from this enlargement, the ampulla, there is sent off the left pore canal. The posterior region draws away from the ampulla but does not separate. The tube which connects this posterior region, the definitive hydrocoele, with the ampulla is the stone canal. This posterior region of the left anterior coelom, the hydrocoele, elongates posteriorly to form two legs and thus appears as an inverted U, from the top and sides of which three outgrowths appear. Just anterior to the tips of the legs, they are joined; and thus a hydrocoele ring is formed with five outgrowths, as those tips of the legs beyond the junction form the remaining two. These outgrowths or primary tube feet develop, in with similar outgrowths from their sides. These outgrowths are the paired tube feet of which at the time of settling down, each radial water tube, as it is now called, may have two pair. The left posterior coelom intermittently gives rise to finger-like outgrowths which become pinched off from the

left posterior coelom. These in turn send invaginations towards the centre of the ring between nerve ring and hydrocoele ring; these evaginations do not fuse but remain, under the hydrocoele ring, a ring of five separate cavities, called the peri haemal ring. The dental sacs persist as papillae throughout the material which has been examined. In the adult there is formed surrounding the mouth a peripharyngeal sinus. In my work I have accounted for the remaining structures of the mouth, and I am led to hope that study of later stages, than those which I have been able to procure, will show that the peripharyngeal sinus is derived in some manner from these dental sacs. The remainder of the structure of the oral surface is derived from an ectodermal invagination, the echinoid pouch, of the left side of the larva immediately above the developing hydrocoele. In the floor of the pouch which is thus formed there developed interradially five ridges from the summits of which outgrowths are developed. These outgrowths meet and roof within this cavity of the echinoid pouch, the amniotic cavity, a five-armed cavity, is formed. The floor of these latter cavities thickens to form the nerves. Thus in the entire mouth of the adult there are the following structures, commencing from the larval stomach, the left posterior coelom, the hydrocoele ring, the perihaemal ring, the nerve ring, the epineural cavity, the epineural fold, or roof of the epineural cavity, and the amniotic cavity. As the tube feet force their way into the amniotic cavity, they carry with them an ectodermal layer formed from the floor of the echinoid pouch. The dental

they receive their stereom in a similar manner. The spines arise from the floor of the amniotic cavity, and the earliest spines appear along the ridges, above mentioned. The dorsal surface is derived from the right side of the larva. The larval arms, and [illegible] disappear, the larval mouth closes. An invagination of the floor of the amniotic cavity becomes the adult mouth, which meets an evagination from the larval stomach, the adult oesophagus. The larval stomach and intestine shrink, and this is accompanied by great enlargement of the coelomic cavities, the walls being henceforth known as mesenteries. The adult assumes an elliptical shape very early after metamorphosis.

CONCLUSIONS.

1. The apical system consists of seven plates, five radials and two basals; each of the two latter plates evidently represents more than a single original basal.

2. There is a single siphon.

3. The development of Moira is very rapid; the second segmentation division occurs one hour after fertilization; metamorphosis takes place in about twenty-two days.

4. The sperm-nucleus rotates as described for other forms; and after rotation, the sperm-aster forms. The sperm-nucleus assumes a vesicular ~~form~~ as it advances towards the female pro-nucleus.

5. The enterocoelic cavities are first pinched off from the archenteric cavity before they divide.

6. There are two pore canals, the right canal opening into the left canal which is first formed.

7. The right anterior coelom persists as a cavity attached to the stone canal near the dorsal pore or madreporite.

8. The hydrocoele ring commences as an inverted U; the legs of the U unite to form the ring.

9. The dental sacs, at the metamorphosis have given rise to five vesicles, which surround the mouth, and the five divisions of the perihaemal ring.

10. There is an apical larval nervous system at the apex of the preoral lobe.

LITERATURE.

(1) A. Agassiz — Revision of the Echini. Illus. Cat. Mus. Comp. Zool. No. VII. 1872-4.

(2) do. — Bibliography of Echinoderms. Bull. Mus. Comp. Zool. Vol. V. 18[illegible].

(3) do. — Report on the Echinoidea dredged by H. M. S. "Challenger" during the years 1873-1876 Report "Challenger" Zoology. Vol. III. 1881.

(4) Beaufort, N. C. — Records of the U. S. Fisheries Laboratory (unpublished).

(5) H. Bury. — Studies in the Embryology of Echinoderms. Quart. Journ. Mic. Sci. Vol. XXIX. 1889

(6) do. — The Metamorphosis of Echinoderms. Quar. Journ. Mic. Sci. Vol. XXXVIII. (N.S.) 1895.

(7) P. H. Carpenter. — On the Apical and Oral Systems of the Echinodermata. Pt. I. Quart. Journ. Mic. Sci. Vol. XVIII 1878.

(8) do. — do. Pt. II Quart. Journ. Mic. Sci. Vol. XIX. 1879.

(9) do. — Some Disputed Points in Echinoderm Morphology. Quart. Journ. Mic. Sci. Vol. XX. 1880.

(10) H. C. Chadwick. — Echinus. Pro. Liverpool Biol. Soc. Vol. XIV. 1900.

(11) H. L. Clark — The Echinoderms of Porto Rico. U. S. F.C. Bull. Vol. XX 1900

(12) do. — The Echinoderms of the Woods Hole Region. U. S. F. C. Bull. 1902.

(13) Delage et Hérouard. Traité de Zoologie Concrète. Tome — Échinodermes. Tome III. 1903.

(14) C. Grave — Ophiura brevispina. Mem. Biol. Lab. Johns Hopkins Univ. 1900.

(15) C. Grave — Feeding Habits of a Spatangoid, Moira atropos, a Clypeastroid [illegible], Mellita quinquesperforata; and a Holothurian, Thyone briareus. Science. Vol. XV 1902.

(16) do. — A Method of Rearing Marine Larvae. Science. Vol. XV 1902.

(17) do. — Some Points in the Structure and Development of Mellita Testudinata. Johns Hopkins Univ. Circulars. 1902.

(18) do. — On the Occurrence among Echinoderms of Larvae with Cilia arranged in Transverse Bands with a Suggestion as to their significance. Biol. Bull. Vol. V 1903.

(19) O. Hamann — Beiträge zur Histologie der Echinodermen. Jena. Zeit. für Naturwiss. Bd. XXI. 1887

(20) R. Koehler — Bull. de la Soc. Zool. de France. Tome XXVI. 1901

(21) A. Lang — Text Book of Comparative Anatomy Pt. II Trans. H. M. and M. Bernard. 1896.

(22) H. Ludwig — Entwicklungen der Asterina gibbosa. Zeit. für Wiss. Zool. Bd. XXXVII. 1882

(23) E. W. MacBride — On Asterina Gibbosa. Quart. Journ. Mic. Sci. Vol. XXXVIII (N.S.) 1896.

(24) do. — The Development of Echinus Esculentus, together with some Points in the Development of E. Miliaris and E. Acutus. Phil. Trans. Roy. Soc. [illegible]. 1903

(25) E. Metschnikoff — Embryologische Mittheilungen über Echinodermen. Zool. Anz. Bd. VII. 1884.

(26) Mortensen — Die Echinodermenlarven der Plankton-Expedition. Bd. II, 1898

(27) Patten — Orienting Small Objects for Sectioning, and Fixing them, when Mounted in Cells. Zeit. für Wis. Mikros. Bd. I, 1884.

(28) Pietschmann — Zur Kenntnis des Axialorgans und der Ventralen Blutraume der Asteriden. Arbeit. a.d. Zool. Inst. d. Univ. Wien. Bd. XVI. 1906.

([illegible]) [illegible]. Wilson — [illegible] und [illegible] der [illegible]. [illegible] für Wiss. Zool. Bd. XXXVIII, 1889

([illegible]) E. B. Wilson — Archoplasm, centrosome, and chromatin in the sea-urchin egg. Journ. Morph. Vol. XI, 1895.

([illegible]) do. — Atlas of the fertilization and karyokinesis of the ovum, 1895.

([illegible]) do. — The Cell in Development and Inheritance. 1896.

([illegible]) E. B. Wilson
A. P. Mathews — Maturation, Fertilization, and Polarity in the Echinoderm Egg. Journ. Morph. Vol. X, 1895.

EXPLANATION OF LETTERS.

ad. st.	adult stomach
a. ent.	archenteron
a. l.	antero-lateral arm
am.	ampulle of tube feet
amp.	ampulla
amn.	amniotic cavity
an.	anus
an. l. s.	skeleton of antero-lateral arm
ap.	apical plate
ap. s.	apical system of plates
ax. or.	axial organ
ba.	basal plate
b. l.	blood lacuna
b. ep.	body epithelium
cal. rd.	calcareous rod
c. c.	cleavage cavity
cae.	caecum
coel.	coelum
d. p.	dorsal pore
d. s.	dental sac
e. c.	entrance cone
ec.	ectoderm
ecr.	excretory tubules
ech. p.	echinoid pouch
e. f.	entrance funnel

endo.	endodermal cells
ent. c.	entero-coelomic cavity
ent.	enteron
ep. c.	epineural cavity
ep. f.	epineural fold
f. f. f. 1, 2, 3	flexure in adult digestive tube
fas.	fascicles of gametes
f. m.	vitelline or fertilization membrane
g. a.	genital aperture
go.	gonad
g. v.	germinal vesicle
int. A.	first part of adult intestine
int. B.	reversed part of adult intestine
l. a. c.	left anterior coelom
l. b.	longitudinal ciliated band
l. hyd.	left hydrocoele
l. m.	larval mouth
l. oe.	larval oesophagus
l. p.	
l. p. c.	left posterior coelom
l. p. ca.	left pore canal
l. std.	larval stomodaeum
m.	adult mouth
md.	madreporite
oe.	oesophagus
mes.	mesenchyme cells

mic.	micromeres
m. p.	middle piece of [illegible] arm
mus.	muscle
n', n'', etc.	[illegible] nerve
n. f.	nerve fibrils
n. r.	nerve ring
oe.	oesophagus
pet.	petaloid
p. d.	postero-dorsal arm
p. d. s.	skeleton of postero-dorsal arm
ped.	pedicillarium
p. h.	perihaemal canal
pl.	plastron
p. l.	post-oral lobe
p. o.	post-oral arm
p. oe. s.	peri-oesophageal sinus
rad.	radial plate
r. a. c.	right anterior coelom
ro.	rod
rec.	rectum
$r. n_1$, $r. n_2$ etc.	radial nerve
r. p. c.	right posterior coelom
[illegible]	right [illegible]
r. w. v_1 etc	radial water vascular tube
[illegible]	[illegible]
se.	sinus surrounding axial organ

si.	siphon of accessory intestine
s. n.	[illegible]
sph.	[illegible]
st.	stomach
st. c.	stone canal
tend.	tendon
t. s.	tuft of spines
u. p.	unpaired posterior arm
u. p. s.	skeleton of unpaired posterior arm
ver.	vertex of test
w. v. r.	water vascular ring or hydrocoele ring
x.	origin of caecum
I, II, III, IV, V.	radial water tubes or primary unpaired tube feet.
1, 2	junctions of siphon with digestive tube.

……………………

Fig. 1. Diagram of Moira atropos in section of sand. Reduced.

Fig. 2. Photograph of Moira atropos to show number of outlet tubes constructed by same animal in aquarium.

Fig. 3. Photograph of surface of sand to show openings of outlet tubes, indicated by arrows. Reduced.

Fig. 4. Photograph of interior of oral half of test, to show arrangement of plates around the mouth (m), arrangement of plates in petal, and the plastron (pl). Nat. size.

Fig. 5. Photograph of interior of aboral half of test. Nat. size.

Fig. 6. Photograph of interior of aboral half of test, to show sunken petaloids. (pet.). Nat. size.

Fig. 7. Photograph of exterior of oral side of test. Mouth (m.). Nat. size.

Fig. 8. Photograph of exterior of aboral side of test. Petaloids (pet.). Apical system (ap.s.). Genital apertures. (g.a.) Madreporite (mad.). Vertex (ve.) Fascioles (fas.) Nat. size.

Fig. 9. Photograph of exterior of left side of test, to show convexity of plates and arrangement of spines. Nat. size. (Figures 4-9, after A. Agassiz).

Fig. 10. Photograph of Moira atropos. x. 1/2

Fig. 11. Internal anatomy from left side, to show the organs of digestion, axial organ (ax. or.), and ambulacral [illegible], (am. [illegible]) x 1 1/2

Fig. 12. Internal anatomy from right side. Gonads (go.). 1 1/2

Fig. 13. Apical system of plates. x15

Fig. 14. Diagram of organs of digestion, from ventral side. x 2.

Fig. 15. Section of mouth of adult through the anterior unpaired radius and posterior unpaired interradius. Perioesophageal sinus (p. oe. s.). x [illegible]

Fig. 16. Disk of ambulacral tube to show digitated edge and calcareous skeletal rods (in outline). x [illegible]

Fig. 17. Calcareous skeletal rod of disk of ambulacral brush. x 1[illegible].

Fig. 18. Transverse section of axial organ, near madreporite. (Fig. 23,18). x 150.

Fig. 19. Transverse section of axial organ, through region of colorless vesicle. (Fig. 23, 19) x 150

Fig. 20. Transverse section of axial organ, through commencement of brown gland. (Fig. 23, 20.) x 150

Fig. 21. Transverse section of axial organ through gland. (Fig. 23, 21.) x 150

Fig. 22. Transverse section of axial organ sinus near oesophagus. (Fig. 23, 22). x 150

Fig. 23. Diagram of axial sinus from Figure 12 to show positions of Figures 18-22. x 8.

Fig. 24. Unmaturated egg of Moira atropos. Germinal vesicles (G. V.). Cytoplasmic rays. x 520.

Fig. 25. Section of fertilized egg (1 min. after fertilization). x 1958

Fig. 26. Section of fertilized egg. (5 min.) Sperm nucleus in rotation. x 1958

Fig. 27. Section of fertilized egg. ([illegible] min.). Pro-nuclei in contact. Centrosome and sperm aster divided. x [illegible]

Fig. 28. Section of fertilized egg. (1[illegible] min.) Fusion of nuclear material. x [illegible]

Fig. 29. Section of fertilized egg. (19 min.) Formation cleavage spindle. x [illegible]

Fig. 30. Section of fertilized egg. (27 min.). Metaphase x 870

Fig. 31. Section of fertilized egg (35 min.) Early anaphase. x 870

Fig. 32. Section of fertilized egg (39 min.) Anaphase continuation of rays of amphiasters with cytoplasmic granules. x 870

Fig. 33. Section of fertilized egg. (39 min. precocious) telophase. Daughter nuclei. Centrosomes divided. x 870

Fig. 34. Section of two-cell stage (51 min.). Metaphase. x 870

Fig. 35. Four-cell stage. Fertilization membrane (f.m.). x 870

Fig. 36. Twelve-cell stage. Micromeres (mic.) x 515

Fig. 37. Longitudinal section of 16-cell stage. Cleavage cavity (c. c.). x 515

Fig. 38. Transverse section of 32-cell stage. x 515

Fig. 39. Longitudinal section of early blastula (3 hrs.) Cleavage cavity (c. c.), vitelline membrane (f.m.), micromeres (mic.) x 515

Fig. 40. Longitudinal section of late blastula. (6 hrs.) Formation of mesenchyme (mes.). x 515

Fig. 41. Longitudinal section of early gastrula (mes.). Archenteric invagination (a. ent.), mesenchymatous musculature (mus.). x 515

Fig. 82. Median longitudinal section of late gastrula. (12 hrs.) Apical plate (ap.). x 410

Fig. 83. Longitudinal section of late gastrula. (15 hrs.) Formation of enterocoele (ent. c.). x 410

Fig. 84. Longitudinal section of late gastrula (18hrs.). Right and left enterocoelic cavities (ent. c.). Definitive enteron (ent.). x 410

Fig. 85. Lateral view of late gastrula (18 hrs.) showing form of larva. x 410

Fig. 86. Longitudinal section of larva (pluteus, 20 hrs.). Larval stomadeum (l.stq.), oesophagus (l.oe.), stomach (st.), and intestine (int.). No opening between stomadeum and oesophagus. x 410

Fig. 87. Larva. (24 hrs.). Posterior dorsal arm (p.d.), postoral lobe (po.l.). x 233

Fig. 88. Larva (18 hrs.) to show skeleton. x 410

Fig. 89. Horizontal section of larva. (36hrs.). Reconstructed from two adjacent sections. Division of enterocoeles. x 410

Fig. 90. Transverse section of larva (48 hrs.). Ampulla (am.), pore canal (p. c.). x 410

Fig. 91. Larva (7 days.) Excretory bodies (ex.), antero-lateral arms (a.l.), postoral arms (po.a.), and rudiment of pre-oral arms (p.o.). x 233

Fig. 92. Reconstruction of transverse sections of larva (8 1/2 hrs.) to show the differentiation of the left enterocoelic cavity. x 233

Fig. 53. Larva ([illegible] hrs.) to show the form of the larval(?) [illegible] the skeleton and the stomach [illegible]. Pre-oral arm (p.o.) x [illegible]

Fig. 54. The left lateral skeletal structure of a larva (1½ days) to show the interlacing of the processes of the bases of the postero-dorsal (p.d.), antero-lateral (al.), postoral (p.o.) arms and the anterior process of the posterior unpaired arm. (a.p.) x 410

Fig. 55. Transverse section of larva (5 days), near posterior unpaired arm. Sphincter muscles (mus.) tendons (tend.), posterior processes of skeletons of the postero-dorsal and anterior lateral arms (rd.). x 410

Fig. 56. Reconstruction of right side of larva (1[illegible] hrs.) to show differentiation of right enterocoele. x 410

Fig. 57. Reconstruction of left side of larva (15days) from horizontal sections to show [illegible]-shaped hydrocoele (l.hyd.) and the left posterior coelom (l.p.c.) which is also assuming the shape of a ring. x [illegible]

Fig. 58. Reconstruction of left side of larva (19days) from lengthwise sections to show hydrocoele ring (l.hyd.), and the rudiments of the primary tube feet (t-f). x [illegible]

Fig. 59. Reconstruction of dorsal side of larva (19 days) in the region of the [illegible] from transverse sections, to show the two pore canals (r.p.ca. and l.p.ca.) x [illegible]

Fig. 50. Longitudinal section of posterior end of larva (? days) to show larval [illegible] [illegible]. Nerve fibrils (n.f.). x 700

Fig. 51. Transverse section of larva (18 days) to show origin of epineural fold (ep.f.). x 440

Fig. 52. Transverse section of larva (18 days). Left pore canal (l.p.ca.), [illegible] (..), stone canal (st.ca.), left hydrocoele (l.hd.), left posterior coelom (l. .c.), and wall of echinoid pouch (ech.p.) x 610

Fig. 53. Transverse section of larva (19 days), to show origin of dental sacs (d.s.). x 530

Fig. 54. Transverse section of larva (about 20 days?). Dental plate (d.p.), radial water tube (r.), nerve (n.), epineural cavity (ep.c.) epineural fold (ep.f.) x 530

Fig. 55. Transverse section of larva (about 22 days?). Hydrocoele ring (l.hd.), [illegible], (..), dental sac (d.s.), peripharyngeal cavity (p. .), adult stomodaeal invagination (ad.st.). x 530

Fig. 56. Transverse section of larva (about 24 days?) to show relationships of structures around the region of the adult mouth. x 1000

Fig. 57. Transverse section of young adult, to show [illegible] of the digestive tube (st.int.), stone canal (st.c.), hydrocoele ring (l. hd.), radial water tubes (r.w.t. . .). x 914.

Fig. 58. Ventral view of young adult, after losing the larval arms. x 120

Fig. 59. Dorsal view of young adult of same age as [illegible]. x 116

VITA.

[illegible] [illegible] was born in Baltimore, Md., [illegible]. He is the son of [illegible] and Florence [illegible]. His preliminary education was received in the public schools of Baltimore. In June 1902, the Johns Hopkins University granted him the degree of Bachelor of Arts. From March 1903 to August 1905, he was an instructor in Biology and Geology in the Illinois Wesleyan University. During the year 1905-1906, he was a student assistant in the Zoological Laboratory of the Johns Hopkins University. His principal ~~[illegible]~~ subject is ~~are~~ Zoology; his subordinate subjects are Botany, and the History of Philosophy.